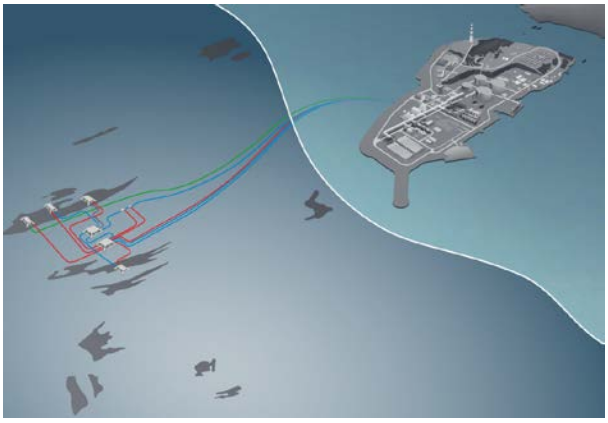
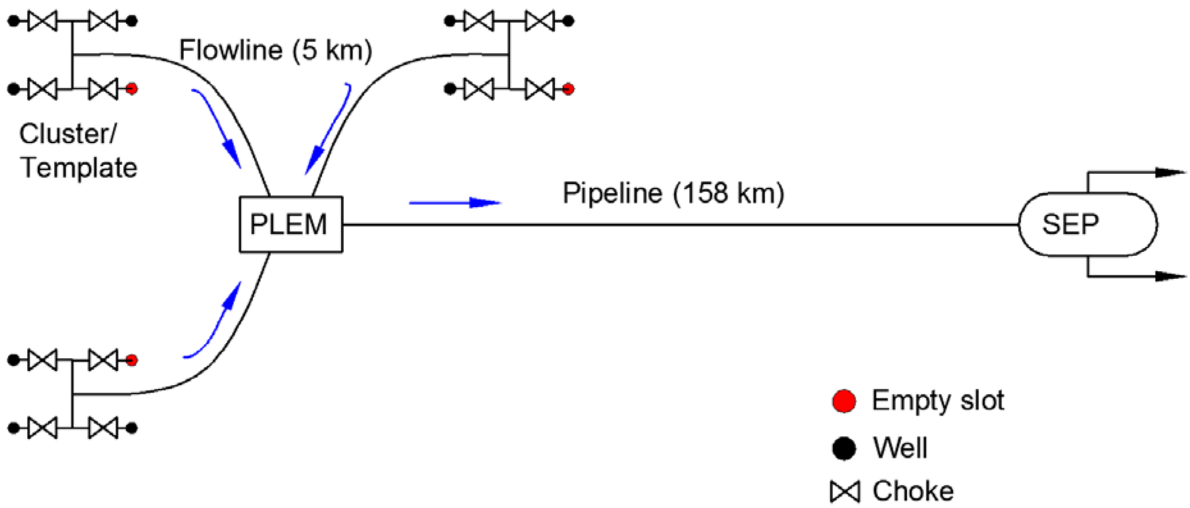
Exercise set 05

PROBLEM 1: Flow assurance analysis of the Snøhvit pipeline using Hysys

Snøhvit is an offshore gas field located in the Barents Sea 158 km from Hammerfest currently under development. The field will be developed with the "subsea to beach" concept. The gas production will be taken by a LNG plant and transported further in LNG carrier to customers in US and Spain. The plateau rate of the field has been set to 20 E6 Sm^3/d and Equinor plans to maintain it until year 2032.



According to the base case Scenario (BCS) selected for the study, the field is completed subsea with three subsea templates, each with 3 wells.



You are asked to perform a steady-state, 1D simulation using the simulator Hysys to compute pressure and temperature drop along the main transportation pipeline from the PLEM to the slug catcher. The main goal is to assess hydrate formation. You have to perform your calculations for two points in time of the system: plateau and decline.

Time [year]	Gas rate field [1 E06 Sm^3/d]	Choke delta p [bara]	Reservoir pressure [bara]
0	20	163	276
26	16	0	97

There is a discussion in the engineering team between using insulated pipeline vs. naked pipe. A recently hired engineer has been arguing that if one uses insulation there might be no need at all of injecting hydrate inhibitor, because the temperature of the gas will be maintained sufficiently high. Investigate this claim.

Tasks:

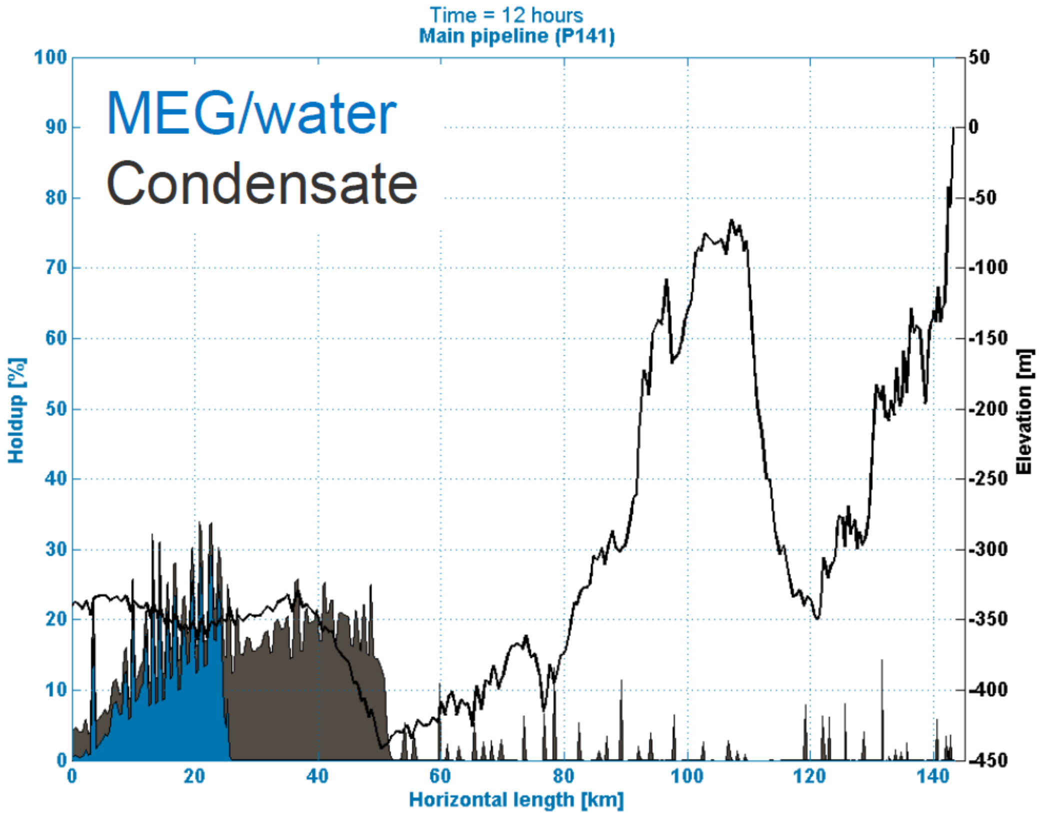
- Tabulate and plot pressure, temperature and liquid holdup along the pipeline. Compute the total amount of liquid in the pipeline.
- Plot the phase envelope (P-T diagram) of the gas mixture illustrating the saturation lines (bubble and dew point lines) and the quality lines inside the two-phase region (0.01, 0.02, 0.03, 0.04, 0.05, 0.1, 0.2). Plot also the hydrate line provided. Indicate in your plot the following:
    - Cricondenbar and Cricondentherm points
    - Plot the p-T along the pipeline on top of the P-T diagram. Detect if there is any condensate retrograde behavior. In this context condensate retrograde behavior is when the liquid stops condensing in the pipeline and it starts evaporating (the quality, mliquid/mtotal, starts to diminish)
    - Will hydrates form in the pipeline? If yes, estimate the amount of MEG that must be injected to avoid the formation of hydrates. Repeat the p-T calculations along the pipeline including MEG. Is there any noticeable difference in the pressure, temperature and holdup profiles obtained?

Solving suggestions

- Remember that Hysys performs its calculations co-current. This means that you provide a pwh pressure, Twh temperature, and a molar rate at the inlet of the pipe, and Hysys calculates the gas flow rates at the exit of the separator and the separator pressure. However, separator pressure has to be 30 bara. In order to force Hysys to reach this value, it is necessary to use an ADJUST.
- Water should be included in your calculations. The well stream is saturated with water at reservoir pressure and temperature (92 ^oC)
- There might be a mismatch between the pressure drop calculations in Hysys and the ones performed previously with Excel. Hysys considers the effect of liquid on the pipe and the variation of density and viscosity of the fluids.
- Use increments of 1 km for your calculations.

Available information

- Pipeline profile. Use the program webplotdigitizer (https://automeris.io/WebPlotDigitizer/) to “steal” the poins from the chart below. Use at least 10 points.



Pout (Slug catcher pressure)	**[bara]**	30
Tseabed	**[C]**	6

Component	**Mole %**
Nitrogen	2.525
Carbondioxide	5.262
Methane	81.006
Ethane	5.027
Propane	2.534
i-Butane	0.4
n-Butane	0.83
i-Pentane	0.281
n-Pentane	0.308
Hexanes	0.352
Heptanes	0.469
Octanes	0.407
Nonanes	0.203
Decanes+	0.397

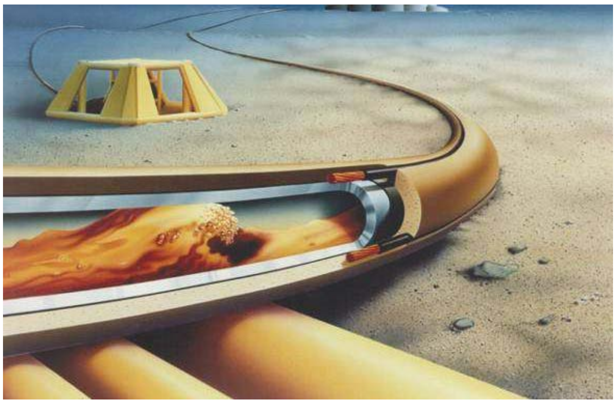
Density of Decane+: 814 kg/m^3
MW of Decane+: 172 kg/kmol

To estimate the overall heat transfer coefficient of the pipeline assuming that the pipe is “naked”, consider:

- Forced convection from the fluid to the pipe wall
- Conduction in the pipe wall
- Free convection with the surrounding seabed.

To estimate the overall heat transfer coefficient of the pipeline assuming that the pipe is insulated, consider:

- Forced convection from the fluid to the pipe wall
- Conduction in the pipe wall
- Conduction in the insulation
- Free convection with the surrounding seabed.



Use the following information:

Inner diameter of the steel pipe ID, [mm]	**678.2**
Outer diameter of the steel pipe OD [mm]	**711.2**
Steel conductivity [W/m K]	**43**
Outer diameter of the Insulation layer OD* [mm]	**777.2**
Insulating material conductivity [W/m K]	**0.22**
Outer free convection coefficient (sea) [W/m^2 K]	**200**
Inner convection coefficient** (Gas cond) [W/m^2 K]	**11**

Hydrate lines					
	wt% MEG:	0	15	35	50
T[C]	**T[K]**	**p[bara]**	**p[bara]**	**p[bara]**	**p[bara]**
-20	253.15	3.7	3.7	6.9	29.0
-15	258.15	4.6	4.6	12.7	102.4
-10	263.15	5.6	5.5	24.2	432.0
-5	268.15	6.9	10.2	51.9	798.6
0	273.15	8.3	18.9	205.3	1212.1
5	278.15	15.5	36.3	487.8	1651.9
10	283.15	28.6	79.8	856.0	2103.3
15	288.15	55.7	243.0	1283.7	2542.2
20	293.15	131.1	507.1	1747.9	2916.2
25	298.15	318.6	855.4	2230.4	3218.9

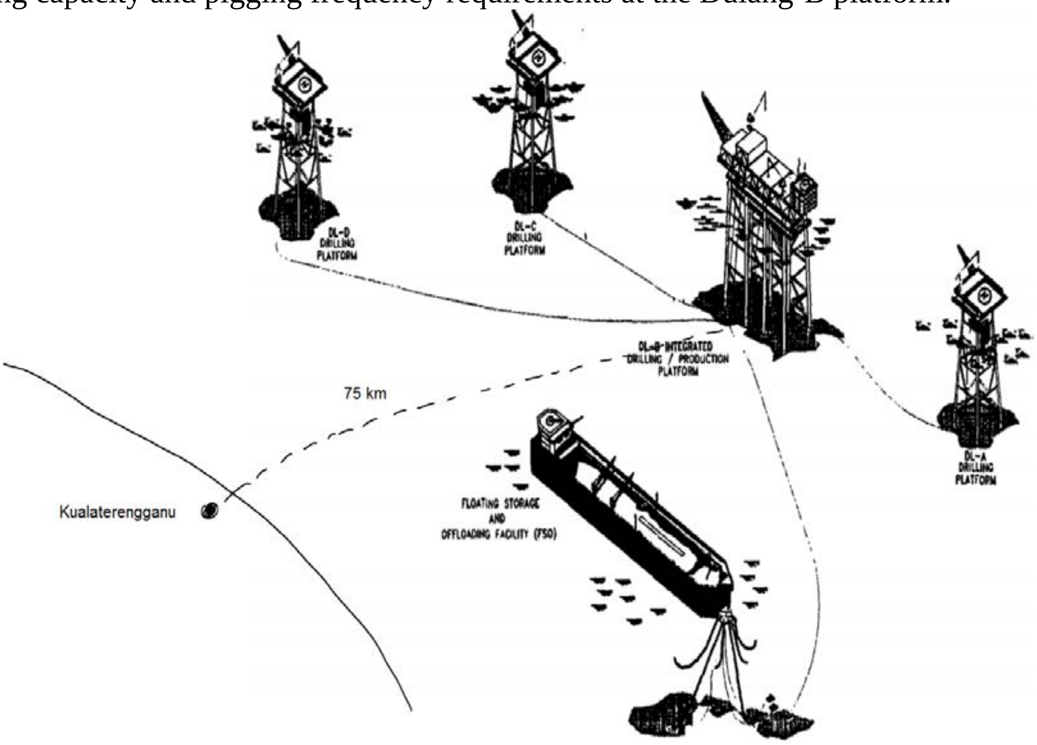
<u>Some help with Hysys</u>:

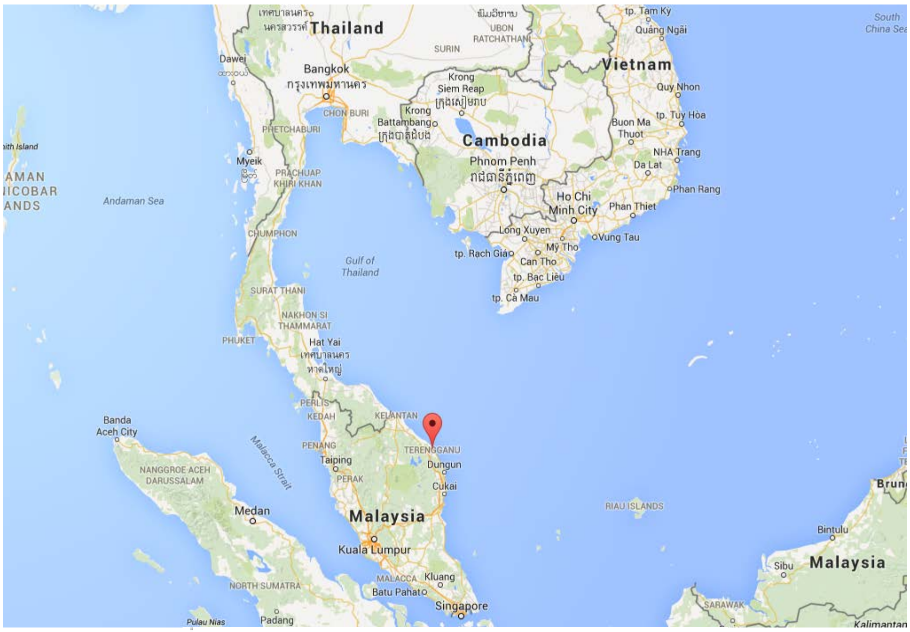
You can run Hysys remotely from your computer using
https://farm.ntnu.no
Alternatively, Hysys is installed in some computers in the computer lab on the 3rd floor.
If you need some help getting started with Hysys, watch the introductory video:
https://www.youtube.com/watch?v=3h6i_K_3yq0

<u>PROBLEM 2:</u> Temperature, pressure and wax deposition calculations in offshore oil export line.

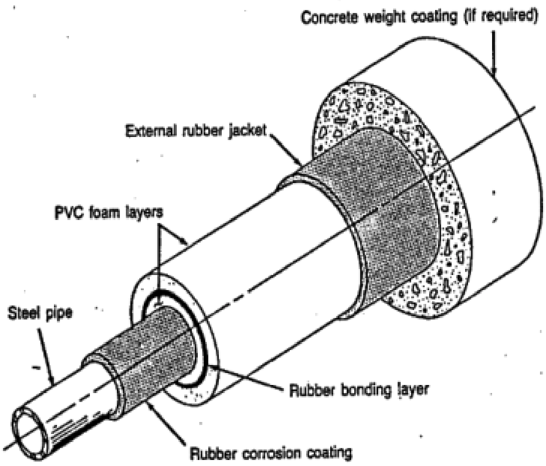
<u>Field Description</u>

The Dulang field is located 75 km offshore Kuala Terengganu in the South China Sea. The reservoir oil has tendencies to form wax crystals and to increase apparent viscosity with reduction of temperature (this is shown in sheet "Mu(T) digitized" in the attached excel file). Two development options are considered for oil export; (1) offshore loading terminal and (2) marine pipeline to shore.
To assess the feasibility of marine pipeline it is necessary to calculate the temperature and pressure profile and wax deposition in the export line at nominal oil flow rate. This to define pumping capacity and pigging frequency requirements at the Dulang-B platform.





Rubber jacket system with PVC foam layers



The pipeline will be unburied, with an insulation coat of concrete that gives an overall heat transfer coefficient of 5 W/m^2 K. The overall heat transfer coefficient is expressed in terms of the outer pipe diameter.

The pressure of the receiving terminal onshore is kept constant at 50 bara. The temperature of the crude leaving the platform is 60 C.

Your tasks are the following:

1. Calculate and plot the temperature and pressure profile of the pipe:

   1.a. Estimate the power required by the pump on the platform assuming that the suction pressure is 5 bara and the pump efficiency is 50%.

   1.b. Will there be any problems with wax deposition along the pipe? Please explain.

2. If wax deposition is a problem, calculate and plot the wax deposition along the pipeline for times 10 days, 30 days, 60 days and 120 days. To make your calculations simpler, assume that the wax doesn't affect the heat transfer coefficient with the sea and neglect the reduction in pipe cross section.

   2.a. If the maximum amount of wax that can be removed from the pipe is 200 kg during a pigging operation. How often is it necessary to pig the pipeline?.

Data and information

-All data required is given in the Sheet "Input Data" in the excel sheet attached.

-Discretize the pipeline in 1000 m steps. Assume the pipeline is horizontal.

-Estimate the pressure drop in the pipe using the Bernoulli equation with head loss and using the Moody friction factor predicted by the Haaland empirical correlation. This equation has already been programmed for you as a VBA function ("Pin" or "Pout", depending if you are calculating pressure downstream a location or upstream a location). Please note that the volumetric rate to use in this function is the **local volumetric rate**, not the standard conditions rate. The local volumetric rate will change will pressure and temperature changes along the pipe. Use the Oil volume factor (Bo) to calculate the local rate. The Bo factor has been already programmed for you as a VBA function ("Bo"). Your pressure calculations must be performed counter-current, as the pressure at the outlet of the pipe is known but not at the inlet.

$$\frac{1}{\sqrt{f}} = -1.8 \cdot \log\left[\frac{6.9}{N_{RE}} + \left(\frac{\varepsilon}{3.7 \cdot D}\right)^{1.11}\right]$$

-Assume that the viscosity of oil is mainly a function of temperature and interpolate on the table provided in sheet "Mu(T) digitized" to find the viscosity at a given temperature. To interpolate the viscosity, you can use the VBA function "tabinterpol" provided (remember to freeze with F4 the input).

-The temperature distribution of an unburied pipeline, with a nearly incompressible liquid can be estimated using the equation below:

$$T(x) = T_{amb} + \left[T(x=0) - T_{amb}\right] \cdot e^{-x/A}$$

$$A = \frac{(\dot{m} \cdot c_p)}{2 \cdot \pi \cdot r_a \cdot U}$$

Where:

T= Temperature of flowing fluid [°C]

x = position in pipe, measured from pipe inlet [m]

T(x=0) = Temperature of flowing fluid at pipe inlet [°C]

Tamb = Ocean bottom water temperature [°C]

m = mass flow rate, [kg/s]

Cp =heat diffusivity of soil, k_e/( ), [m^2/s]

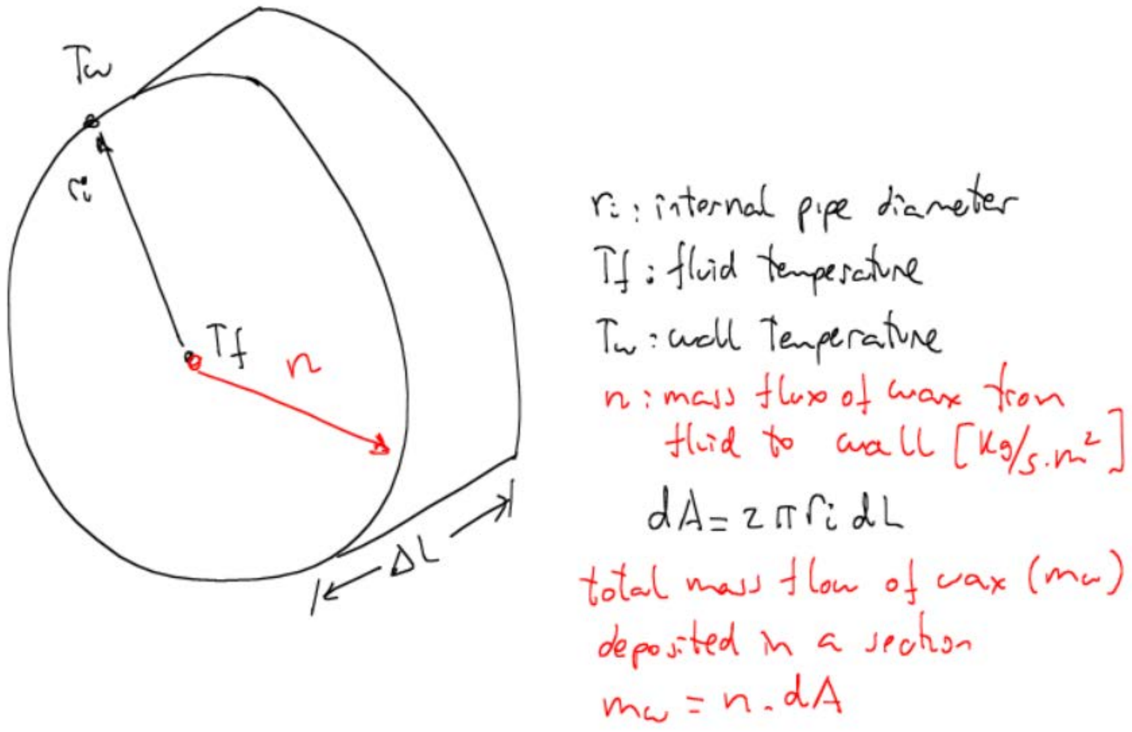
ra = External radius of the conduit (with insulation) [m]

c_p = heat capacity of flowing fluid, [J/kg °C]

U = Overall heat transfer coefficient [W / m^2 °C]

-Assuming the main wax deposition mechanism is molecular diffusion and that all wax that precipitates out of solution will immediately deposit, the wax deposition rate (n in kg/s / m^2) can be estimated using the equation below:

$$n = \rho_{wax} \cdot \frac{B}{\mu_o} \cdot \frac{dC}{dT} \cdot \frac{dT}{dr}$$



REMEMBER: there will be wax deposition only when the temperature of the fluid goes below the WAT!

Where:

rho_wax = wax density [kg/m^3]

mu_o = oil viscosity [Pa s]

B = molecular diffusion coefficient [N] (provided in the excel sheet).

dC/dT = wax solubility coefficient [1/C] (provided in the excel sheet).

dT/dr = temperature gradient [C/m]

Estimate the temperature gradient dT/dr as the difference between temperature of the fluid and temperature of the inner pipe wall.

-The temperature of the inner pipe wall can be estimated from the expression:

$$\dot{q} = 2 \cdot \pi \cdot r_i \cdot h_i \cdot \left(T_{fluid} - T_{innerwall}\right)$$

Where:

q = heat per meter, [W/m]

r_i = pipeline inner radius [m]

h_i = forced convection heat transfer coefficient inside the pipe [W / m^2 K]

T_{fluid} = fluid temperature [C]

$T_{innerwall}$ = temperature of pipe inner wall [C]

-For your calculations, assume the forced convection heat transfer coefficient is constant. The value is provided in the sheet "Input data" in the attached excel file.

-Remember that the heat per meter can also be calculated from the overall heat transfer expression:

$$\dot{q} = 2 \cdot \pi \cdot r_a \cdot U \cdot \left(T_{fluid} - T_{amb}\right)$$